The Population/Biodiversity Paradox. Agricultural Efficiency to Save Wilderness

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"I know of no time which is lost more thoroughly than that devoted to arguing on matters of fact with a disputant who has no facts but only very strong convictions" (Simon, 1996). The comment aptly summarizes a common experience (including my own) in dealing with technophobes. In one sense, the genetic manipulation (GM) debate can only be conducted on a level in which the participants are prepared to enlarge their knowledge and refine their views accordingly. I consequently have tried in this article to provide plenty of facts that can be used in discussion with reasonable participants. My recommendation is to forget those who are not prepared to modify in any way a prepared (i.e. ideological) position.

My own view of GM is that its primary use to mankind must come initially in helping to solve fundamental problems that currently present themselves. These outstanding problems concern population, global warming, and biodiversity. In a longer version of this article I have tried also to provide some critique of current trends toward placing ecological views into agriculture in the hope of generating reasoned discussion. The full version of this article is on my web site (www.ed.ac.uk/~ebot40/main.html). All the information below can be obtained from the referenced articles, although I have not always indicated where.

BASIC ISSUES TO BE APPROACHED

Human Population Increase

The United Nations' median population assessments are for 8 billion human beings by the year 2020 (United Nations, 1998; Pinstrup-Andersen et al., 1999); these figures are considered the most likely population scenario. The increase in the population in the next 20 years is expected to be 2 billion (35× the population of the UK; 8× the population of U.S.; 1.3% per year) and common humanity requires us to ensure adequate nutrition for these extra people where this is politically feasible. The largest absolute population increase is estimated to be 1.1 billion in Asia, but the highest percentage increase is expected in sub-Saharan Africa (80%). By 2020 more than 50% of the developing world's population will be living in urban areas instead of the 30% at present. Enormous problems in the production, distribution, and stability of food products will be generated and some of these problems require inputs from scientists (Pinstrup-Andersen et al., 1999). India is a prime example of these likely problems: 70% to 80% of the population currently farm traditionally and simply eat all that they grow. By 2025, India will be the most densely populated country in the world with 1.5 billion people and grossly swollen cities. Radical changes in Indian agriculture, transport, and food preservation would seem to be essential to avoid serious nutritional catastrophe.

An annual increase of 1.3% in food production is necessary at the present time to feed the burgeoning human population, assuming present diets remain invariant. However, richer populations eat more meat and a doubling of cereal yields may instead be necessary (Smil, 2000). Annual increases in cereal production, currently slightly below 1.3%, are predicted to continue to decline with the most serious food shortages in sub-Saharan Africa and the Middle East (Dyson, 2000). Most developing countries will have to lean heavily on imported food as they do now. Approximately 120 out of 160 countries are net importers of food grain (Goklany, 1999). In turn, a critical requirement is a genuine free trade in food, a situation that has still not been achieved.

Cropland and population are not uniformly distributed (for example, China has 7% of the world's arable land and 20%–25% of the world's population), which will exacerbate future problems. However, predicted rises in crop yields will not come about without policies that attach high priority to agricultural research (Alexandratos, 2000; Johnson, 2000), particularly as many developing countries desire self-sufficiency in food production. Worldwide funding for agricultural research has declined substantially in the last 20 years. These problems are exacerbated by diminishing cropland area due to erosion (for alternative view, see Johnson, 2000); fewer renewable resources, such as potassium and phosphate; less of, and consequently more expensive, water (by 2050, it is estimated that one-half the current worldwide rainfall on land will be used for industry and agriculture); and a reduced population working the land (Kishore and Shewmaker, 2000).

Global Warming May Be Global Warning

We have stretched current ecosystem stability to the limit by the destruction of wilderness and fixed carbon in forests (Tilman, 2000). Continued combustion of coal and oil has ensured a steady increase in global-warming carbon dioxide levels. 1998 was the warmest year in the last millennium (Crowley, 2000). Predictions suggest average global temperatures will rise by 2°C to 3°C by 2100 with, more menacingly, increasing fluctuations in extreme weather conditions. The world climate is a complex hierarchical system and analysis and prediction lean heavily on the properties of nonlinearity, chaos, emergence, feedback, attractors, and self-organization (Stanley, 2000, and references therein). The properties of such systems are often strongly counterintuitive and at the best can only be based on probabilities of outcome (Trewavas, 1986). Simple solutions; banner waving; and using this form of agriculture and not that, which are proposed by elevating the importance of one factor without reference to the whole, are likely to produce dangerous or destabilizing results if acted on fully. Similar nonlinear difficulties attend attempts to construct world population and food production futures.

Arctic ice core analyses indicate the world climate can cross thresholds and jump to new stable temperature states in fractions of a decade (Stanley, 2000). One prediction, with a respectable probability, suggests cessation of the Gulf Stream with some worrying indications already reported in the salinity of the deep ocean (Edwards, 1999). The Gulf Stream maintains average temperatures 5° higher for parts of Europe. Cessation could be disastrous for those countries affected (including my own) and would require an agricultural revolution to be instituted in a few years. Most climate models predict a steady rise in temperature, but the accuracy of prediction is constrained by lack of detailed information.

Climate change can radically alter rainfall patterns and necessitate large-scale population movement and primary changes in agriculture. Such dramatic climate changes are known to have occurred in the past in the Mediterranean region (for example, abandonment of Troy and Petra) and in parts of Meso-America in the 6th century A.D.

None of us will be immune to climate-change effects. Elevated ocean levels resulting from polar ice cap melting will ensure that substantial portions of land will disappear in low-lying areas, such as Bangladesh and Florida. Because many large cities are ports, and thus at sea level, increased flooding from weather extremes are more probable. Increased storm activity, floods, and long-term droughts (currently three years in Sahel, Ethiopia) will stretch agricultural resources and threaten local food production. Such situations may lead to wars. Two to 3 years of breakdown in monsoon patterns could, for example, cause nuclear exchange in Asia in arguments over limited food resources. Excessive heat frequently kills susceptible people and exacerbates respiratory problems. Tropical diseases such as malaria, the West Nile virus (which visited New York recently), dengue, and others may move outwards from the tropics as temperatures climb (Epstein, 2000). All this against a backdrop of variable volcanic activity known to alter climate patterns, sometimes drastically, with 100 volcanoes around the world capable of doing real damage (Crowley, 2000). Are the present fluctuations in climate the first rumblings of a breakdown in the feedback circuitry that controls global climate?

Atmospheric carbon dioxide has been increasing for over 100 years. How much of the increase of this global-warming gas is the direct result of human activities is still argued, but most have now concluded that it may be primary. Plowing up yet more wilderness, cutting down forests, or increasing the area of land under agriculture, thereby increasing the loss of fixed carbon, is no longer a viable option to solve population food problems. Furthermore, methane and nitrous oxide are far more damaging to global warming than carbon dioxide on a mole-for-mole basis. The primary land-based origin of these gases is anaerobic breakdown of organic material (particularly in rice paddies), bacterial activities in the digestive systems of cows, and microbial degradation of agricultural manure. The U.S. alone generates an estimated 1.3 billion tons of manure per year (Nagle, 1998). Some rethinking about the drive to organic farming with its heavy dependence on manure is urgently required.

The Kyoto 1997 Agreement is designed to control worldwide carbon emissions, although there is skepticism over whether such an agreement can be policed and achieved. This is not a good time for anyone to consider abandoning new agricultural technologies such as GM or to turn the clock back to organic kinds of agriculture.

Maintenance of Biodiversity

Technological progress driven by the forces of technological change, economic growth, and trade is a prime cause of the problems facing biodiversity. The demands of an increasing human population are responsible for diversion of water, wilderness destruction, water quality problems, and accumulations of pesticide residues. Fragmentation of habitat and loss in turn places major burdens on the world's forests and terrestrial carbon stores and sinks (Goklany, 1998). Many species have been placed under stress and there is possibly a higher rate of species extinction now than previously, although this is contentious (Simon and Wildavsky, 1984). However, species extinction is not a necessary adjunct of large human populations. Relatively small numbers of human beings apparently eliminated mammoths, mastodons, the moa in New Zealand, the dodo, some 100 species (10%) of plants in Hawaii (Raven, 1993), and others some 25,000 years ago. Biodiversity has direct economic value. Pimentel et al. (1997) estimate that biodiversity contributes $100 billion to the U.S. economy each year.

TO SOLVE THE POPULATION/BIODIVERSITY PARADOX, IT IS NECESSARY TO ENSURE THAT FUTURE FOOD REQUIREMENTS COME ONLY FROM PRESENT FARMLAND

To conserve the present ecosystems, increased food production must be limited to the cropland currently in use. Goklany and Sprague (1991) argue that conserving forests, habitats, and biodiversity by increasing the efficiency and productivity of land utilization represents a sensible alternative to sustainable development. This view is powerfully echoed by Avery (1999), who argues that recourse to less efficient forms of agriculture, for supposed environmental reasons, will result in plowing up of yet more wilderness and cutting down forest to feed the increasing population. However, the best land is almost certainly in agricultural production; what is left is usually of poor quality and likely to produce poor yields.

Smil (2000) has indicated that to feed the increase in population expected by the year 2050 with traditional agriculture (relying as it does for the basic mineral resources on limited recycling, rain, and biological nitrogen fixation) would require a 3-fold increase in land put down to crops. Tropical forests, much of the remaining temperate forests, and most remaining wilderness consequently would be eliminated with disastrous effects on atmospheric carbon dioxide. In contrast, feeding the increase in population could result in extreme damage to ecosystems unless farms are increasingly seen as small ecosystems with efficient recycling of minerals and water (Tilman, 2000). Use of renewable micro-energy sources would be beneficial. However, the Haber-Bosch process of chemical nitrogen fixation is completely sustainable if solar sources of energy are used.

Although increasing efficiency as a conscious strategy to reduce environmental impacts is virtually an article of faith for the energy and materials sector, it has received short shrift for agriculture, forestry, and other land-based human activities. Many institutions (e.g. green organizations) and strategies that would conserve species and biodiversity are conspicuously silent on the need to increase the efficiency of farmland use (Goklany, 1999). Either they do not understand the policy, or improving efficiency contradicts their desire to impose some less-efficient, supposedly ecological solution on agriculture. However, the consequence of less-efficient agriculture will be the elimination of wilderness that by any measure of biodiversity far exceeds that of any kind of farming system. It is the fundamental contradiction in current environmental arguments (Huber, 1999).

Broad technological progress is also necessary to ensure that affluence is not synonymous with environmental degradation by helping to create the technologies and financial resources needed to reduce pollution and natural resource inputs of consumption across the board. Readier availability of the necessary technology and fiscal resources will also help translate the probably universal desire for a cleaner environment into the political will for public measures.

How Have Technological Improvements in the Past Helped to Preserve Wilderness?

From 1700 to 1993 there was an 11-fold increase in human population but only a 5.5-fold increase in cropland area (Table I). The recent improvements in agricultural efficiency brought about by technology can be seen when comparing the figures from 1961 to 1993 (Table II). An approximate doubling of the world population has been gained without massive starvation and with a barely detectable increase in cropland. The agricultural yield has been a per capita increase, over and above the increase in population and this must remain as one of the major technological achievements of the last century.

The total estimated land in use as farmland in 1993 was 4,810 Mha. Much of this land is rough grazing and of poor soil quality with toxic levels of aluminum toxicity or low pH. But in total, 36% of the land surface (excluding polar caps) of the globe is farmed. Farming is the largest land management system on earth.

If we had frozen technology at 1961 levels, to feed the 6 billion in 2000 we would need to increase the cropland area by 80% (910 Mha), thus converting 3,550 Mha (an additional 27% of the land surface) to agricultural uses (Goklany, 1998). This calculation assumes that new lands would be as productive as present cropland, which is unlikely. The effect on atmospheric carbon dioxide levels would be disastrous. This putatively additional farmland exceeds net global loss of forest since 1961 (143 Mha) and matches the increase in cropland since 1850 (910 Mha). Ausebel (1996) estimated that wilderness the size of the Amazon basin has been saved by technological improvements since 1960. Technological improvements in U.S. agriculture in the last decades have ensured that 80 Mha of farmland has been returned to wilderness in the U.S. (Huber, 1999). If U.S. agriculture had instead been frozen at 1910 levels (part organic technology) then it would need to harvest at least an extra 495 Mha to produce present

Table I. *Some important facts and figures about crop yields and population*

	1700	1993
Population (billions)	0.5	5.5 (11-fold)
Cropland (area)	270 Mha	1,450 Mha (5.5-fold)

Table II. *Some important facts and figures about crop yields and population*

	1961	1993
Population (billions)	3	5.5 (1.85-fold)
Cropland (Mha)	1,340	1,450 (1.1-fold)
Average/capita food production (Kcals/d)	2,235	2,699
Protein/capita (gm/d)	62	71
Malnourished (millions)	917 (35%)	839 (21%)
Food prices (%)	100	47
Cereal yields (%)	100	196

levels: more than the present cropland and forest combined.

Many technological developments have given rise to this huge improvement in yield and thus the saving of wilderness. Without pesticides, 70% of the world food crop would be lost; even with pesticide use, 42% is destroyed by insects and fungal damage (Pimentel, 1997). Dispensing with pesticides would require at least 90% more cropland to maintain present yields. Yields from irrigated fields are three times those from nonirrigated crops (Goklany, 1998). In 1960, 139 Mha were irrigated and in 1993 this amount had increased to 253 Mha. Without irrigation, 220 Mha of extra cropland would be required to feed the current population. Because application of fertilizer can increase yields by anywhere from 1.5- to 2-fold, dispensing with fertilizer would require at least an extra 400 to 600 Mha of cropland (Smil, 2000). Without these technologies, current food production would only have been achieved by plowing up an extra 2,000 Mha!

The Downside of Technological Progress: Problems to Be Solved

Water has been diverted for irrigation and industry, but often used wastefully (Evans, 1998). On average only 45% of irrigation water reaches crops (Goklany, 1999). In 1997 the Yellow River (China) ran dry for 200 d as a result of low rainfall and extraction for industry and agriculture. The Colorado River has not reached the sea for many decades. Eutrophication and oxygen depletion caused by nitrogen and phosphate leaching from agricultural lands has resulted from the profligate use of manures and fertilizers (Smil, 1997). Stable pesticide residues are now much lower than 30 years ago because the chemical industry ensures that new pesticides are biologically unstable. Pesticide residues are detected rarely now in vegetables but it is more common that one or a few residues can be detected in about one-half of supermarket fruits at levels 100- to 1000-fold below safe recommended limits. However, current procedures for application are wasteful; only 1% of pesticides is thought to land on target.

Technological progress to solve the above problems is now necessary to help ensure that a growing human population does not squeeze out the rest of nature in the process. Abandoning technology is not the answer; improving technology to remove the hazards ensures continued benefit to both mankind and the environment. Integrated crop management systems (Chrispeels and Sadava, 1994) that optimize the use of pesticides, minerals, and water offer the best potential for future conventional agriculture to achieve yield increase without waste.

THE ENVIRONMENTAL TRANSITION

The vital basics of life are warmth, food security, freedom from disease, and long life. These basics require a high standard of living and people are prepared to ignore the environmental impacts of industrialization until the basics are achieved. Figure 1 indicates the development through various simple designations of either economic or agricultural structure from agrarian, industrial, and knowledge-based/service economies now prevalent in the west. Most damaging environmental effects are associated with the dominance of heavy industry and large-scale, intensive agriculture necessary to feed large numbers of people. No form of agriculture is really environmentally friendly because wilderness is eliminated and diversity is largely replaced by crop monocultures.

The environmental transition is marked by reductions in emissions such as sulfur dioxide (i.e. acid rain) from industry. There is also a change in perception from Mother Earth, providing an abundance of resources, to Spaceship Earth, with its limitations in provision. The "ultimate resource," human ingenuity and creativity, is not limited but increases with pop-

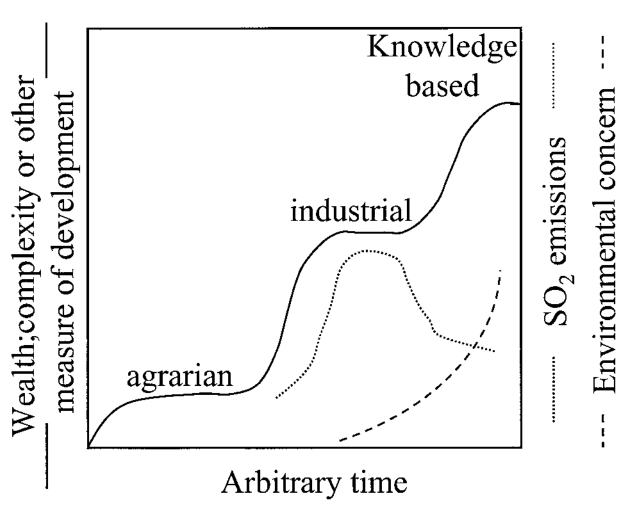

Figure 1. A diagrammatic indication of the relationship between economic development and environmental concern. The three primary economic systems of agrarian-, industrial-, and knowledge-based service are indicated with arbitrary indications of wealth and development. SO_2 emission is used merely as an indicator of industrial development and the subsequent environmental concern generated.

ulation numbers. The concept of Spaceship Earth is drawn from ecology and may be completely invalid for many natural resources (Simon, 1996).

Detection of environmental problems requires advanced technology and equally advanced technology and wealth to solve the problems. There will always be problems until individual ambition is satisfied. Economic growth is commonly blamed for much environmental degradation (Myers, 1997). Economic growth is not synonymous with quality of life nor an end in itself, but merely the means by which all individuals advance their quality of life for themselves and their children. But until the majority of nations pass through the environmental transition, the overall quality of the planetary environment is unlikely to improve. No government is going to agree to rules and conditions that keep their population poor. It would certainly be hypocritical for rich nations to impose constraint on others who have not yet achieved the fundamental basics of human existence. To impose such views would be tantamount to yet another example of western cultural domination. The misinformation about GM to third-world countries by current activist groups is just such an example. It is fortunate that many countries have decided to ignore the propaganda.

Living in harmony with nature, a theme of new-age groups, is a possibility that disappeared some 5,000 to 10,000 years ago and is not sought by many in poorer nations. One can, if he or she wishes, live in harmony, but one will live in poverty if one lives at all. The present wealthy and complex western societies require large numbers of people to carry out the necessary highly diverse tasks.

DOES HIGHER POPULATION GROWTH INCREASE HABITAT CONVERSION?

"The battle to feed all of humanity is over. In the 1970s and 1980s hundreds of millions of people will starve to death in spite of any crash program embarked upon now" (Ehrlich, 1968). Like Malthus before him, Ehrlich failed to appreciate that technological advances negate predictions of gloom. This time the green revolution intervened. Pressure from population increase, economic necessity, and the mere statement of the problem usually throws up solutions. It is notable that critical advances in agricultural technology, such as agricultural engineering, recognition of mineral requirements for plant growth, the Haber-Bosch process for ammonia production, and the green revolution all occurred at times in which food provision and population problems were pressing. Predictions could have been made over 100 years ago that burgeoning populations and business in London would result in the city being knee deep in horse manure (Huber, 1999). It is fortunate that the internal combustion engine intervened preventing potentially dangerous levels of ammonia toxicity!

The impact of plant breeding improvements and the green revolution rice and wheats are responsible for much of the recent increased yield (Table I). Increased yields in India indicate the achievement. In 1950, India produced 1,635 Kcal per day per person and in 1963 produced 2,069 Kcal per day per person. The recommended minimum is 2,300 Kcal per day per person and a recommended average is 2,700 Kcal per day per person to ensure that virtually all have an adequate diet. In 1950, India produced 6 million tons of wheat and in 1998 produced 72 million tons. The total land area of India is 292 Mha and from 1961 to 1998 the population doubled to 1 billion. However, the per capita production from 1961 to 1998 actually increased by 16% (green revolution crops) and the cropland increased only from 161 to 170 Mha (Goklany, 1999).

If food production had been kept at 1951 levels (as argued by green revolution critics such as Shiva [1991]), then the requirement for cropland by 1998 would have exceeded India's land mass (thereby eliminating all wilderness and forest) or massive starvation would have been unnecessarily inflicted. In fact, Indian forest and woodland expanded by 21% between 1963 and 1999 (Goklany, 1999). The claims by Shiva (1991) that "the food supplies (in India) are today precariously perched on the narrow and alien base of the semi-dwarf wheats" have been shown to be merely polemic and have no scientific basis. The number of land races dramatically increased with the green revolution; the resistance of green revolution cereals to rust is much greater than previous varieties (Smale, 1997).

Those who constantly agitate for the worldwide introduction of primitive and frankly "land-guzzling" forms of agriculture must answer this basic question: How would their form of agriculture have fed the burgeoning human population? Although recognizing that the world produces a slight excess of food (about 8% over consumption), without the agricultural efficiency of western agriculture (the main exporters), most countries of the world would have experienced serious food shortages and the attendant human illnesses that go with starvation. Sentiment is no substitute for a full belly.

All technologies have problems because perfection is not in the human condition. The answer is to improve technology once difficulties appear; not, as some would wish, discard technology altogether. Remove the problems but retain the benefits! The benefits of modern agricultural technology are well understood; now is the time to reduce the undoubted side effects from pesticides, soil erosion, nitrogen waste, and salination. GM technology certainly offers some good solutions.

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